An Automatic and Recording Torsion Measuring Apparatus

H. J. Scherr / W. E. Palm

There is a need for an automatic and recording apparatus that will measure torsional modulus versus temperature. Although an apparatus described by Wilson[1] is automatic, its function is to measure the elastic recovery of materials which possess kinetic elasticity. Commercial versions of torsion instruments such as the Gehman[2] and the Clash-Berg[3] employ a turret to hold several specimens which are tested consecutively. These still require manual indexing and testing of the specimens. Williamson[4] suggested that his torsion wire instrument could be made automatic and recording and showed a design for testing four specimens simultaneously but nevertheless manually. Since none of these instruments could be considered automatic or recording, an apparatus was designed and constructed which can be used to test leather and plastics according to ASTM Test for Stiffness Properties of Nonrigid Plastics as a Function of Temperature by Means of a Torsion Test (D 1043 – 61 T).

Structure and Mechanics

Figures 1 and 2 show the mechanical structure and components. At the base of the structure is a U-shaped pedestal of box construction which contains the switches and pilot lights for the control relays and stirring motor and also a male receptacle for the bath heating element. A metal box on this pedestal contains the relays for the automatic cycling control and also a switch to initiate the cycle manually. The pedestal supports a hollow steel post on top of which is an aluminum cagelike structure (two parallel plates separated by four corner posts) which holds and supports the transducer, torsion motor, cams and microswitches, stirring motor, heating element, thermocouples, and lower clamp support bar. The latter is a steel bar fastened to the lower plate of the cage to provide support for the lower specimen clamp yoke. The yoke restrains the lower clamp and hence the specimen from rotation about the longitudinal axis, yet allows it to move vertically thus preventing tension loads in the specimen, especially at the lower temperatures. The lower clamp yoke can be moved lengthwise along the support bar to accommodate specimens from one to six in. in length.

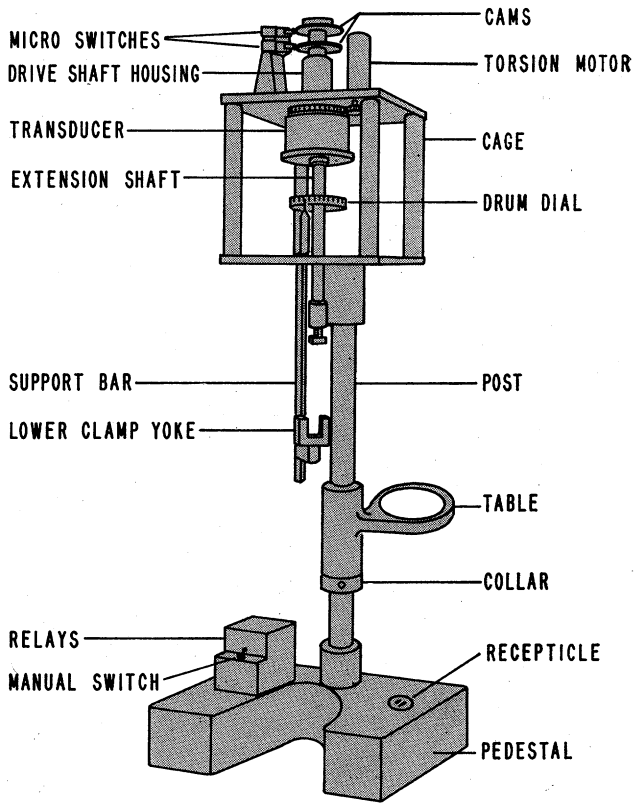

Fig. 1—Sketch of mechanical structure and components.

[1] Wilson, Angus, "Measurement of Rubber Elasticity at Low Temperatures Using a Twist Recovery Apparatus," **Technical Report 66-4-CM,** Clothing and Organic Materials Division, U. S. Army Natick Laboratories, Natick, Mass., 1966.

[2] Gehman, S. D., Woodford, D. E., and Wilkinson, C. S., Jr., "Low Temperature Characteristics of Elastomers," **Industrial and Engineering Chemistry,** Vol. 39, No. 9, 1947, pp. 1108–1115.

[3] Clash, R. F., Jr. and Berg, R. M., "Vinyl Elastomers Low Temperature Flexibility Behavior," **Industrial and Engineering Chemistry,** Vol. 34, No. 10, 1942, pp. 1218–1222.

[4] Williamson, I., "An Improved Instrument for the Evaluation of the Physical Properties of High Polymer Compositions," **British Plastics,** Vol. 23, No. 256, 1950, pp. 87–90, 102.

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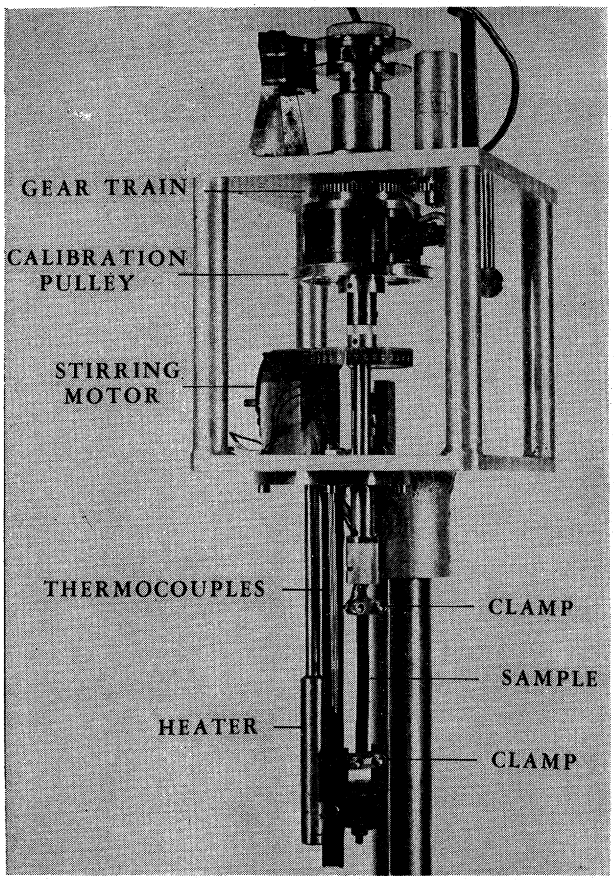

Fig. 2—Photograph showing details of instrument.

Between the pedestal and the cage is a pivotable table supported by an adjustable collar. This table serves as a holder for a Dewar flask that contains the temperature control medium.

The mechanical arrangement is such that the transducer (a reaction torque sensor) is connected end-to-end with and applies torque to the specimen and is therefore part of the twisting mechanism itself. To accomplish this a drive shaft is attached to the end of the transducer opposite to and coincident with the torque sensing shaft. The drive shaft is supported in a plain bearing housing on the upper plate of the cage. This arrangement permits the transducer to rotate about its sensing shaft axis. The upper specimen clamp is joined to the sensing shaft by an extension long enough to lower it into the Dewar flasks. Loading of the specimen in the upper clamp is facilitated by a telescoping arrangement that permits the clamp, which is keyed to the extension shaft, to move axially on it. Fastened to the extension shaft is an aluminum pulley used for dead weight calibration. Also on this same shaft is a drum dial used for setting the cams to obtain a selected angle of specimen twist.

The drive mechanism consists of a simple gear train (spur and pinion) on the transducer and motor with a ratio of 2:1. The drive motor is a geared d-c motor having a maximum torque of 10 oz-in. Power for this motor is supplied by an adjustable, regulated power supply. With the above arrangement a specific rate of specimen twist can readily be obtained. The rate used herein was 90 deg in 10 sec as suggested by Williamson.

Automatic Control Mechanism

Figures 1 and 2 further show the automatic control mechanism for the twist cycling. This consists of two adjustable cams mounted one above the other on the transducer drive shaft. A microswitch is operated by each cam causing the start-stop and reversing relays to function.

A schematic for the automatic test cycling control is shown in Fig. 3. Two sources of electrical energy are required for this system: 115 V ac for the relay coils (*a, b*) and 24 V dc for the drive motor. The twisting cycle is initiated when the normally open (NO) microswitch is shunted by a normally open electronic relay within the programmer. The (NO) switch is the holding contact for the complete test cycle. After the required 90 deg twist is reached, the normally closed (NC) microswitch causes the motor to reverse, returning the specimen to zero twist. The latching switch, which is part of the reversing relay, holds the system in the reverse mode. When the specimen again reaches zero twist, the latching (NO) microswitch opens, terminating the automatic cycle until it is again initiated by the programmer. Due to an unavoidable on dwell of the programmer function switch that conflicts with the total on time of the automatic test cycle, a delay circuit was added to the automatic test cycling control to return the specimen at a slower speed than that used for the loading cycle.

Basic Design of the Instrumentation

The block diagram of Fig. 4 shows the functional relationship of the electronics and associated equipment. The heart of the system is a dual function programmer which controls both the rate of temperature increase in the bath and also initiates the automatic test cycle. The programmer's basic function is to supply a command signal to the proportional controller which also receives a feedback signal from the control thermocouple in the bath. The controller then supplies the heater with the proper current to obtain the selected temperature rate increase (3 C/min) of the specimen bath. The temperature program is started at the lower temperature of the selected range and increased, as recommended by Williamson, to avoid freezing in of strains in the specimen; it is also easier to increase the temperature than to decrease it. A monitoring thermocouple follows the bath temperature and registers the test temperature on a dual channel recorder.

The other function of the programmer is to trigger the automatic test cycling system described earlier. This is done with a program function switch PFS which triggers the automatic system at every 5 C increase of the temperature bath. The programmer employed herein is not limited to 5 C temperature increments but is adjustable within limits. Twisting the specimen causes an mV signal to be produced by

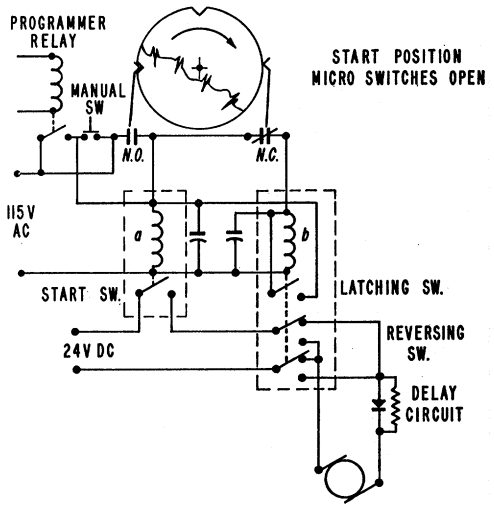

Fig. 3—Schematic of automatic test cycling circuitry.

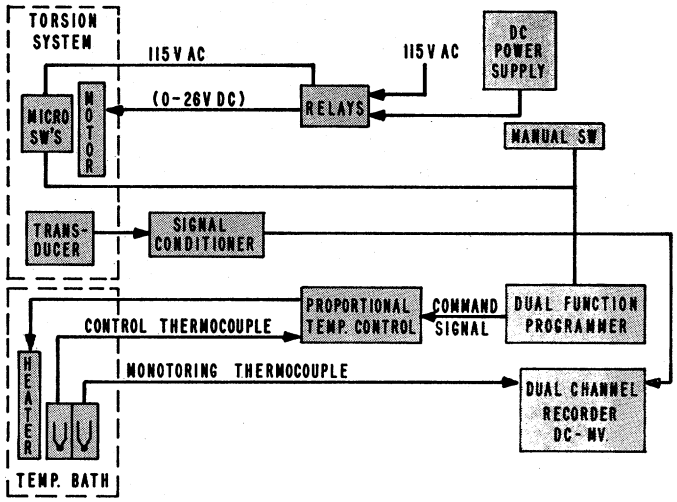

Fig. 4—Block diagram of electronic and associated components.

the transducer-signal conditioner system. This signal is then fed to the other channel of the recorder.

The stress developed during the test cycle is measured by a reaction torque sensing transducer. It is a strain gage bridge type with a capacity of 0 to 100 oz-in. The sensing shaft of the transducer has a very high torsional constant requiring only ¼ deg twist for the full transducer capacity of 100 oz-in. This feature is important to insure that the real angle of twist subtended by the upper and lower sample clamps will be essentially the applied angle of twist. A strain gage signal conditioner supplies the transducer bridge with a regulated adjustable d-c voltage and in addition provides the necessary circuit adjustments to adapt the transducer to a d-c mV readout instrument.

Calibration of the load sensing system is made by means of a weight attached to the calibration pulley shown in Fig. 2. With a weight suspended from the pulley, the span control of the conditioner and the sensitivity control of the recorder are adjusted together to obtain the proper scale on the recorder. Dead weight calibration can be supplemented by a calibrated resistor connected across one arm of the strain gage bridge.

It is advisable to have a zero offset control on each channel of the strip chart recorder. The channel recording the transducer signal should be offset to show the specimen's recovery after each twisting cycle.

Experimental

The automated apparatus was evaluated by comparing its performance with that of an established manual instrument used to measure torsional stiffness. The manual instrument used is described in ASTM D 1043–61 T and also by Clash and Berg.

In order to carry out the above, four samples of poly(vinyl chloride) (PVC) were prepared. These contained 10, 20, 30, and 40 percent of di-2 ethylhexylphthalate (DOP), respectively, as the plasticizer along with stabilizers.

A separate specimen from each sample was tested in each instrument using similar test procedures and temperature programs. As stated earlier the automated instrument was programmed for a temperature rise of 3 C per min with testing of the specimen (90 deg twist in 10 sec) occurring at every 5 C increase. These same parameters were approximated (depending on the skill of the operator) with the manual apparatus. The temperature for both instruments ranged from —60 to 60 C.

A sample of recorded data obtained with the automatic instrument is shown in Fig. 5. The dependent variable measured is peak reaction torque (stress) in g-cm. The temperature of the specimen at each peak torque is read from the temperature curve at the point where it intersects the perpendicular from the torque peak to the time axis of the chart. Note that the trace falls below zero on the return part of the test cycle, then gradually recovers toward zero torque before the start of the next cycle. From this part of the trace a measure of the recovery of the material with respect to temperature can be obtained.

Although the automatic instrument measures stress, and the manual instrument strain (angle of twist), both measurements should give approximately the

same apparent stiffness in torsion.

To convert the recorded data (reaction torque versus temperature) into apparent torsional stiffness in psi units, the following formula is used: $E_G = T\ (2.39\ L/Wt^3\mu\theta_s)$

where

E_G	= apparent stiffness in torsion, psi,
T	= measured reaction torque, g-cm,
2.39	= conversion factor,
L,W and t	= the length, width and thickness, respectively, of the specimen, in.,
μ	= shape factor (value depends on ratio of width to thickness), dimensionless, and
θ_s	= twist of specimen, deg (90 deg generally selected)

The modulus data obtained from the above tests is plotted in Fig. 6. It can readily be seen there is very good agreement in the shape of each pair of curves regardless of the percent plasticizer used in the PVC. Measurements made with a manually operated torsion wire apparatus

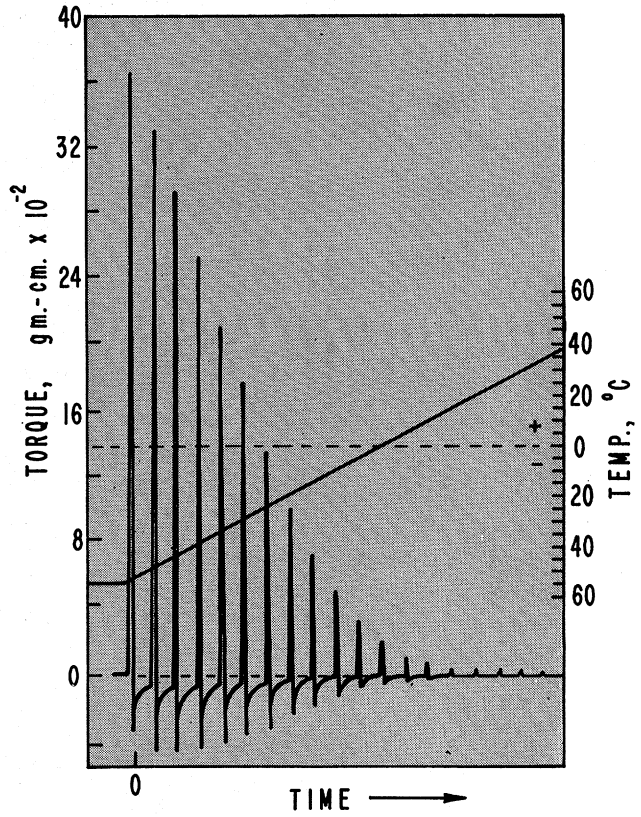

Fig. 5—Recorder trace obtained with automatic instrument. Specimen PVC plus 30 percent DOP.

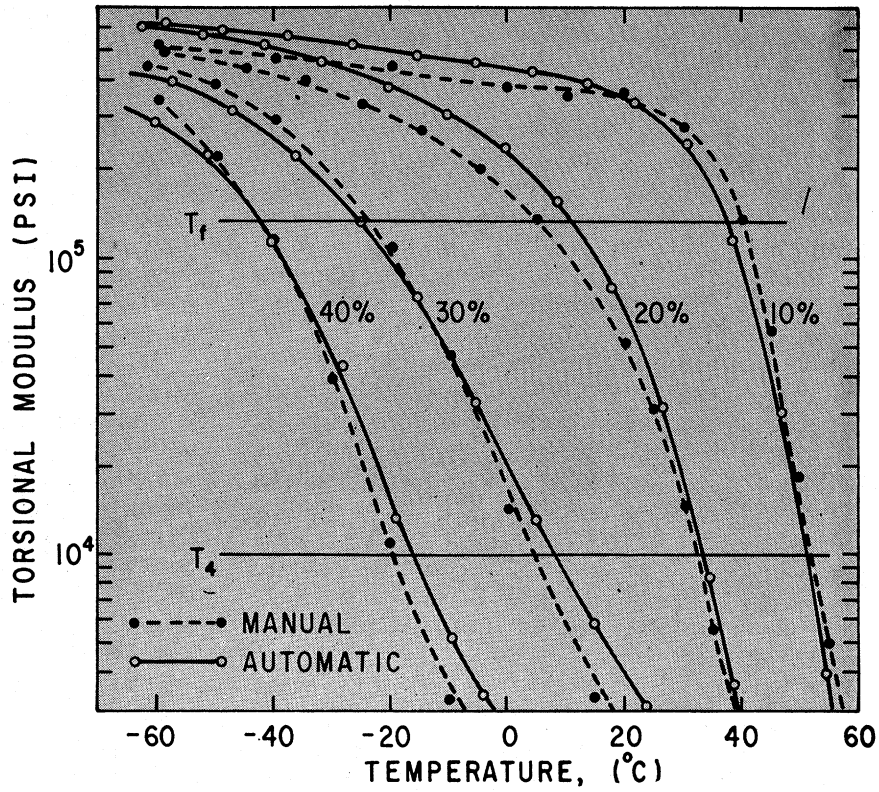

Fig. 6—Comparison of torsion moduli obtained from the automatic and manual instruments. Materials tested were plasticized with 10, 20, 30, and 40 percent DOP.

when compared with the automatic instrument measurements showed similar agreement (data not shown).

Table 1 shows the T_f (135,000 psi) and T_4 (10,000 psi) temperatures for the four samples and two instruments.

Table 1—Comparison of T_f and T_4 Temperature Data, Manual and Automatic Instruments

DOP[a]	T_f Temperature		T_4 Temperature	
	Manual	Automatic	Manual	Automatic
%	deg C	deg C	deg C	deg C
10	40	37	52	52
20	7	11	33	34
30	−24	−25	5	8
40	−42	−42	−20	−16

[a] Sample composition polyvinyl chloride (PVC) plus di-2 ethyl-hexyl-phthalate (DOP)

Conclusion

The apparatus described herein yields data comparable to that obtained from manual torsion measuring instruments presently in use. It is more precise because the temperature rate (increase) is controlled by a programmer, the torque (specimen twist) is applied at a controlled rate, and the reaction torque due to the applied twist is measured by a strain gage transducer.

Furthermore, the recorded data shown in Fig. 5 demonstrates the advantage of having a recorded set of data. This plot not only shows the load (stress) versus temperature but also the recovery pattern of the specimen as it relates to temperature. This recovery versus temperature data warrants further study.

Acknowledgment

The authors wish to thank R. R. Calhoun, Jr., for constructing and assistance in designing the mechanical structure.

REFERENCE: Scherr, H. J., and Palm, W. E., **"An Automatic and Recording Torsion Measuring Apparatus,"** *Materials Research & Standards,* MTRSA, Vol. 8, No. 12, pp. 13–17.

ABSTRACT: An automatic and recording torsion measuring apparatus was developed to increase the efficiency, convenience, and precision of measuring torsional modulus versus temperature of leather and polymeric materials. A dual channel programmer continuously controls the temperature (increase) in a specimen bath and at the same time initiates an automatic twisting (strain) cycle to the specimen at every 5 C temperature increment. Automatic test cycling is attained with microswitches, relays, and cams. The load (stress) sensing part of the apparatus is based on a strain gage reaction torque sensor. The performance of the automatic unit was compared with that of a manually operated instrument by testing four plasticized compositions of polyvinyl chloride in each instrument.

KEY WORDS: torsion measurement, temperature programming, automatic sequence testing, reaction torque sensor

Discussion

Reliable Technique for Determining Plastic Limit[1]

J. G. E. Nuyens/R. F. Kockaerts

Richard McGaw[2]—In view of the variation which has been shown to occur among individual determinations, [*1*],[3] the supplementation of the Atterberg plastic limit test with a consolidation test, as proposed by Nuyens and Kockaerts, deserves consideration. However, further tests will be required before a decision can be made as to the validity of the proposed consolidating pressure.

It is unquestioned that a water content equal to that at the plastic limit can be attained by consolidating from a semi-liquid state. Nuyens and Kockaerts show that, for the soils tested and for clay contents below 40 percent, the required consolidation pressure is in the range 10 to 20 kg/cm^2; a pressure of 14.4 kg/cm^2 produces saturated water contents in the range PL $\pm$ 1.7 percent moisture. Whether this precision is more acceptable than that of the usual plastic limit determination is debatable. Beyond that, however, lies the question of whether a single value of consolidating pressure can be expected to produce the plastic limit water content over a large range of soils. For clay contents greater than 40 percent it appears quite possible; on the other hand, data given in the literature make it appear unlikely that such will be the case for the lower range of clay contents.

Baver [*2*] showed that plastic limit decreases with increasing clay content, for clay contents less than 30 percent. Davidson and Handy [*3*] found that plastic limit is essentially proportional to clay content, for higher percentages of clay. Ballard [*4*] performed careful tests over the entire range from 0 to 100 percent clay, with similar results. However, noticing the similarity between the plastic limit relationships and Norton's packing diagram for binary mixtures, he presented the hypothesis [*4, 5*] that the plastic limit is basically a packing phenomenon occurring in the saturated condition. He showed that the plastic limit for clay contents less than 40 percent is determined primarily by the packing density required by the non-clay fraction while undergoing deformation; and further, that plastic limit in this range increases with the angularity of the non-clay particles.

Seed et al [*6*] demonstrated that liquid limit possesses packing characteristics. Working by analogy

[1] Nuyens, J. G. E., and Kockaerts, R. F., "Reliable Technique for Determining Plastic Limit," **Materials Research & Standards,** MTRSA, Vol. 7, No. 7, July 1967, pp. 295–299.

[2] Research engineer, Earth Sciences Branch, Department of the Army, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

[3] The italic numbers in brackets refer to the list of references appended to this discussion.